Quaternary International 371 (2015) 122–134

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Isotopic and micromorphological studies of Late Quaternary loess–paleosol sequences of the Karewa Group: Inferences for palaeoclimate of Kashmir Valley

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ARTICLE INFO

Article history:
Available online 26 November 2014

Keywords:
Pedogenic carbonate
$\delta^{13}C$
$\delta^{18}O$
Micromorphology
Slope gradient
Climate change

ABSTRACT

Pedogenic carbonates, widespread in paleosols throughout the geological ages, have been widely used to infer climatic conditions and vegetation type during their formation. They are ubiquitous and widespread in the Late Quaternary loess–paleosol sequence of the Kashmir Valley, mostly in the form of carbonate nodules. In the present study, pedogenic carbonates are studied to analyze trends in the stable isotopic composition of carbonate nodules across three well-developed loess–paleosol sections in the Kashmir Valley. The stable carbon isotopic ($\delta^{13}C$) analysis reveals a gradual increase of the C_4 vegetation towards the top of the sections. The development of C_4 plant biomass towards the top of sections possibly reflects water stress and/or reduced atmospheric pCO_2 and increasing aridity. The oxygen ($\delta^{18}O$) isotopic analysis reveals little variation with the values ranging from −6.37‰ to −7.75‰, reflecting stable climatic conditions during the development of pedogenic carbonate nodules. The use of geospatial data including digital elevation model (DEM) and Landsat TM remote sensing imagery have added morphological characterization of the topographic and landform features observed in the area. The tectonic uplift of the Pir Panjal Range, variation in the geometry of Karewa Basin and the slope gradient have played a key role in the spatial variation of loess–paleosol sequences in the valley. The Late Quaternary climate changes, deposition of loessic sediments, formation of the interbedded paleosol profiles and the subsequent denudation processes have resulted in the present day typical geomorphic landscape of the Kashmir Valley. The micromorphological analysis of loess–paleosol horizons reveals cold arid to semi-arid climatic conditions prevailed during the Late Quaternary in the valley.

1. Introduction

Loess covers ~10% of the earth's surface, and includes terrestrial records of interglacial–glacial cycles (Porter and An, 1995; Palmer and Pillans, 1996; Muhs et al., 1999; Porter, 2001; Ahmad and Chandra, 2013; Obreht et al., 2014). Loess deposits typically consist of alternating loess beds formed by silt deposition under cold and arid climatic conditions, whereas paleosols develop during warm and humid interglacial climatic conditions (Liu, 1985; Holliday, 1990; Pant, 1993; Shackleton et al., 1995; Derbyshire et al., 1998; Tang et al., 2003). Morphological and chemical properties of paleosols can provide a wealth of information about past environmental conditions. In addition to being an indicator of landscape stability, paleosols can also provide information about palaeoclimate and associated vegetation type (Cerling et al., 1989; Gupta et al., 1991; Kraus, 1999; Wynn, 2000, 2004; Pustovoytov and Terhorst, 2004; Feng and Wang, 2005; Behrensmeyer et al., 2007; Quinn et al., 2007; Levin et al., 2011; Retallack, 2013).

Pedogenic carbonate nodules in paleosols provide excellent terrestrial archives of palaeoecological and palaeogeographic reconstruction, as well as past atmospheric CO_2 concentrations (Frakes and Jianzhong, 1994; Wang et al., 1997, 2000; Hatté et al., 1998; Wang and Follmer, 1998; Muhs et al., 1999; Johnson and Willey, 2000; Pustovoytov and Terhorst, 2004; Gocke et al., 2010). The stable oxygen isotope ($\delta^{18}O$) in carbonate nodules is mainly controlled by the temperature and the composition of the water in the soils, whereas the carbon isotope ($\delta^{13}C$) is characterized by the type and extent of local vegetation cover (Cerling, 1984; Quade et al., 1989a, 1994; Quade and Cerling, 1995; Cerling et al., 1997;

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http://dx.doi.org/10.1016/j.quaint.2014.10.060
1040-6182/

Quade and Lois, 1999; Achyuthan et al., 2007; Behrensmeyer et al., 2007; Rahaman et al., 2011). The $\delta^{18}O$ and $\delta^{13}C$ signatures of the carbonate in paleosols have also been used to estimate average annual temperature, the isotopic composition of precipitation and the relative proportions of C_3 and C_4 plants growing at any given time (Rowe and Maher, 2000; Gocke et al., 2010; Zhou and Chafetz, 2010).

It is now well established that carbonate-containing paleosols are widely distributed across arid and semi-arid regions of the world, with records extending back to several million years (e.g. Cerling et al., 1989; Quade et al., 1989b, 2004; Rowe and Maher, 2000; Levin et al., 2004; Bera et al., 2010). The late Quaternary loess–paleosol sequences of Dilpur Formation of the Karewa Group are widely distributed in the Kashmir Valley. These sequences are characterized by well preserved pedogenic carbonate nodules in large numbers with the diameter ranging from less than 1 cm–10 cm. They are mostly sub-spherical, but vertically elongated forms also exist. Most of the previous studies on loess–paleosols of the Kashmir Valley have focused on the lithostratigraphy, micromorphology, geochemistry, mineral magnetism, infrared stimulated luminescence (IRSL) and radiocarbon dating (Bhatt, 1976; Burbank and Johnson, 1982, 1983; Singh, 1982; Singhvi et al., 1987; Pant et al., 2005; Ahmad and Chandra, 2013; Dar et al., 2013a). However, the stable carbon isotope ratio of organic carbon and pedogenic carbonates from loess–paleosol sequences have been studied by Krishnamurthy et al. (1982) to infer the palaeoclimate of the Kashmir Valley. However, these first carbon isotopic measurements are based on limited data. Therefore, keeping in view the role of pedogenic carbonates for inferring palaeoclimatic reconstructions, an integrated analysis of lithostratigraphic, micromorphic and isotopic data of pedogenic carbonates in loess–paleosol sequences was undertaken to develop a better and deeper understanding of the palaeoclimatic, palaeoecological and palaeogeographic reconstruction of the Kashmir Valley.

2. Study area

2.1. Geological setting

The intermontane Kashmir Valley lies between the Great Himalayan Range to the northeast and Pir-Panjal Range to the southwest. Geologically, the valley possesses almost complete stratigraphic record of rocks of all ages ranging from Archean to Recent. However, Panjal Volcanic Complex and the Triassic Limestone form the two main geological formations, overlying the Archean metasedimentary rocks (Salkhala Formation). The tectono-geomorphic setting of the valley reveals that due to the rise of the Pir-Panjal Range, the primeval drainage was impounded as a vast lake, known as the Karewa Lake. This lake received sediments from the surrounding uplifted mountain ranges which were later on named as Karewa Group of sediments (Bhatt, 1982). The sediments of Karewa Group are fluvial, glacio-fluvial and lacustrine in nature ranging in age from the Pliocene to Pleistocene (Kotlia, 1985a; Bronger et al., 1987; Kotlia and Koenigswald, 1992; Basavaiah et al., 2010) and have been extensively studied by various workers from time to time over the past few decades (Bhatt, 1976; Kotlia et al., 1982, 1998; Burbank, and Johnson, 1983; Agrawal et al., 1985, 1989; Kotlia, 1985a,b, 1990, 1992, 2013; Sahni and Kotlia, 1985; Kusumgar et al., 1986; Kotlia and Mathur, 1992). Loessic sediments of the Dilpur Formation occur as cap deposits to these sediments (Pant et al., 2005). These loessic sediments interbedded with paleosol profiles are characteristics of the whole region, and a general chronostratigraphy has been developed for these sediments (Bronger et al., 1987; Singhvi et al., 1987; Agrawal et al., 1988; Rendell et al., 1989; Gupta et al., 1991; Ahmad and Chandra, 2013). These sediments provide a unique opportunity to study the basin evolution in response to climate changes during the Late Quaternary.

2.2. Stratigraphy and depositional setting

The loessic deposits of the Dilpur Formation form an important litho-unit in the Karewa stratigraphy. These sediments are distributed throughout the valley and occur as terraces, slope and plateau deposits. Among all the loess deposits, plateau deposits are considered to be ideal for the reconstruction of lithostratigraphy as they provide a complete stratigraphic sequence and can be laterally correlated. The field observations reveal that the loess exposures on the Pir-Panjal side show a continuity of longer records compared to those on the Himalayan side. The loess sequence on the Pir-Panjal side is superimposed on the gravel bed of the Shopian Member of the Upper Karewa. However, towards the Himalayan side, these loessic sediments cap the Upper Karewa laminated silt of the Pampore Member. In the present study, three representative loess–paleosol sections at Shankerpora Village (33°50′N–74°57′E) and Putkhah Village (34°14′N–74°28′E) both located along the southwestern part of the Valley and Khan Sahib Village (74°65′N–33°93′E) located in the central Kashmir were chosen for detailed studies (Fig. 1). The Shankerpora and Khan Sahib sections hold the complete and best records of the terrestrial loess–paleosol sediments deposited over the Shopian Member of the Karewa Group during Middle to Late Pleistocene; whereas the Putkhah section represents the Upper part of the loess–paleosol sequence lying above the lacustrine sediments of the Pampore Member.

2.3. Climate

The uplift of the Tibetan Plateau at ~14 Ma is regarded as the causative factor for monsoonal system in Asia (Edwards et al., 1996). This uplifted mountain range has resulted in a change in precipitation and monsoonal climate within the Indian region (Ganjoo and Shaker, 2007) and is responsible for the strong latitudinal gradient of increasing aridity towards the central parts of the Himalaya and Tibetan Plateau (Wünnemann et al., 2008, 2010). However, upliftment of the Pir Panjal Range has played locally a major role in determining the climatic changes in the Kashmir Valley. The 1400–5000 m uplift since the past ~4 million years in the Pir Panjal Range (Burbank and Johnson, 1983; Agrawal, 1987) has effectively blocked the southwestern monsoon winds and changed the climatic conditions from tropical to more arid to windy in the valley. The present-day rainfall pattern in the valley is dominated by winter precipitation brought in by western disturbances (WD) as opposed to the southwestern monsoons prevalent in most of the Peninsular India. The WDs are most active during winter and spring and decrease substantially as summer progresses.

The average annual precipitation in the study area is 710 mm and the average annual temperature is 13.5 °C (Dar et al., 2013b). With absence of any Global Network of Isotopes in Precipitation (GNIP) station in Kashmir Valley, the modelled $\delta^{18}O$ of precipitation established by Bowen and Revenaugh (2003) reveals that study area is influenced by Westerlies, as most depleted $\delta^{18}O$ values are found during winter and spring season. This is further supported by instrumental precipitation data showing more than 60% precipitation during winter and spring season (Fig. 2).

3. Materials and methods

During the detailed field studies, loess–paleosol sequences were identified and differentiated on the basis of morphological features (i.e. color, texture, structures and boundary type). Various